

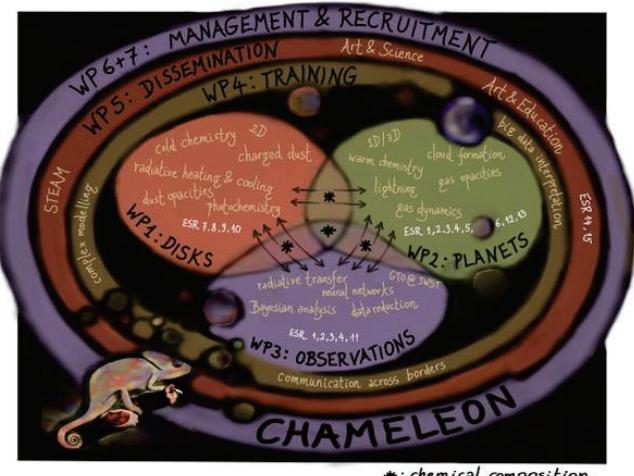
# THE CHAMELEON MC ITN EJD FINALE



**MARIE CURIE ACTIONS**

OEAW.AC.AT/IWF

CHAMELEON: November 2020 kick-off → August 2024 finale



Marie Skłodowska-Curie  
Innovative Training Network (ITN)  
for European Joint Degrees (EJD)



## CHAMELEON Virtual Laboratories for Exoplanets and Planet-Forming Disks

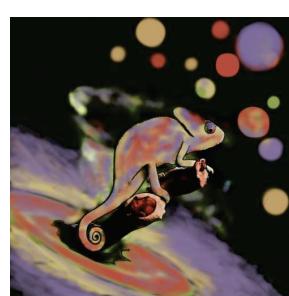
6 European beneficiaries



KU LEUVEN

THE UNIVERSITY  
OF EDINBURGH

15 PhD students



4 European partner institutions



Dutch Space Research Institute



SCHOOL OF ARTS



# CHAMELEON

## Virtual Laboratories for Exoplanets and Planet-Forming Disks

CHAMELEON:



MC ITN EJD  
MARIE CURIE ACTIONS

WP 1:  
Modelling planet-forming disks  
(Peter Woitke, Graz)



WP 2:  
Modelling exoplanet atmospheres  
(Leen Decin, Leuven)

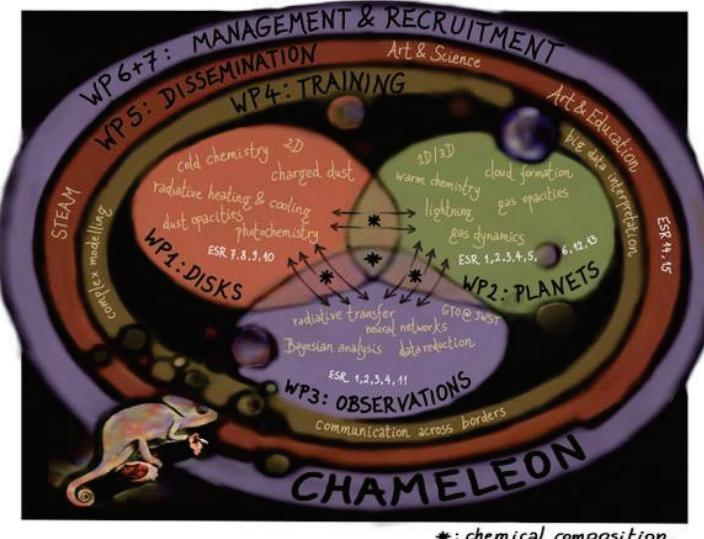


WP 3:  
Predicting observations & Data analysis  
(Uffe G. Jørgensen, Copenhagen)



OEAW.AC.AT/IWF

3



\*: chemical composition

CHAMELEON:



MC ITN EJD  
MARIE CURIE ACTIONS

### Scientific output:

120 entries on ADS  
(40 ESR first authored)  
+ observational proposals  
(JWST etc.)

### Scientific network events:

3 CHAMELEON Schools  
24 Network research meetings  
44 Supervisor meetings  
5 Supervisor board meetings  
33 ESR meetings  
2 ESR retreats



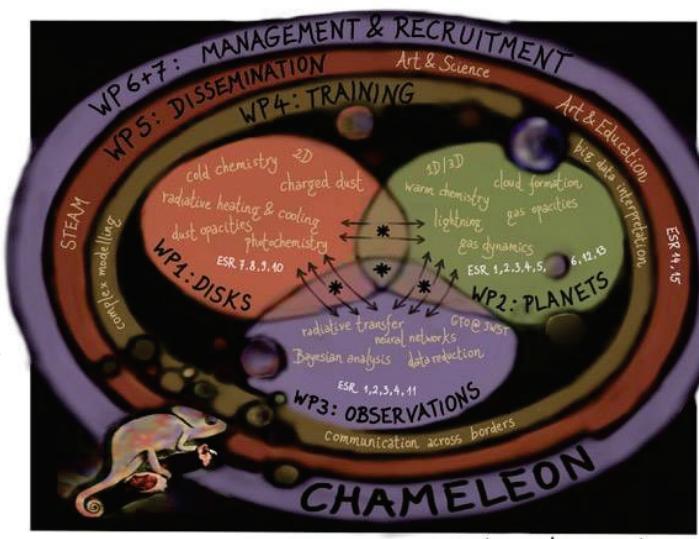
### PhD degrees:

3 finalized (= 3 new Dr.s)  
3 submitted  
4 about to be submitted  
Wanted: 15 Dr.s

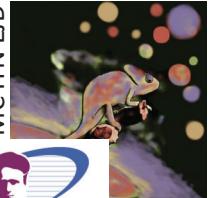


OEAW.AC.AT/IWF

4



\*: chemical composition



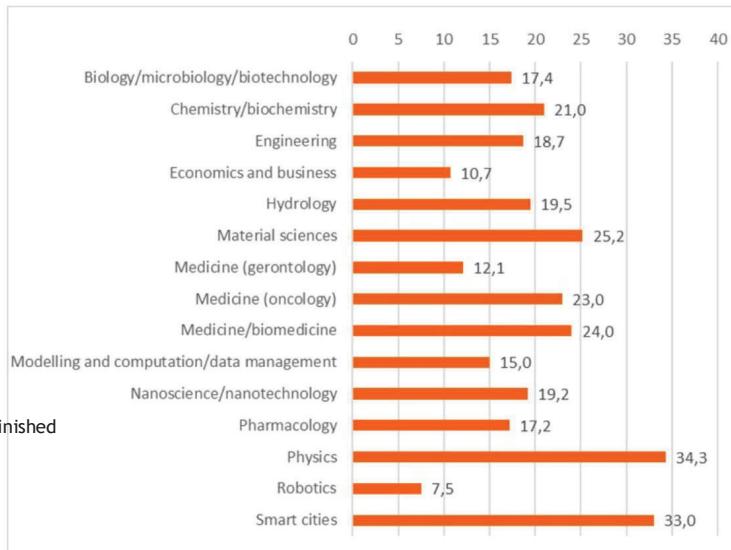
MC ITN EJD  
MARIE CURIE ACTIONS

## CHAMELEON Achievements in the context of EU survey of MC ITNS

domain averaged  
publication numbers

MC ITN 2014-2017, all finished  
118 projects analysed

(Bitsios et al. 2023)



OEAW.AC.AT/IWF

5

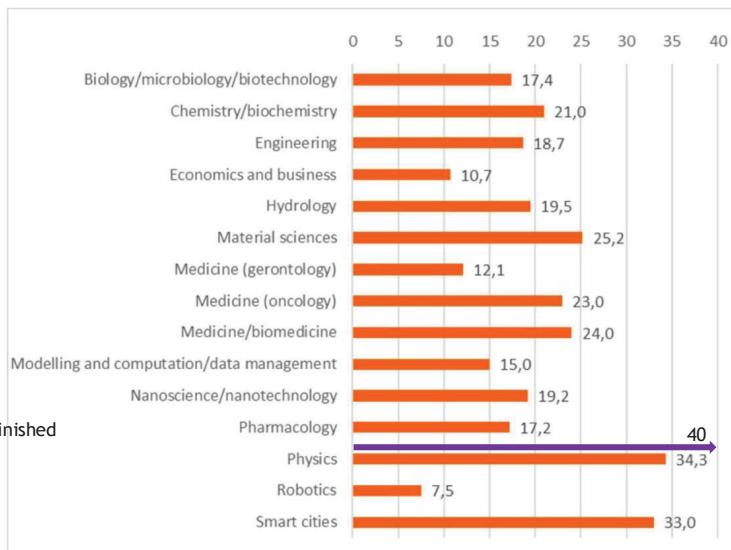


## CHAMELEON Achievements in the context of EU survey of MC ITNS

domain averaged  
publication numbers

MC ITN 2014-2017, all finished  
118 projects analysed

(Bitsios et al. 2023)



OEAW.AC.AT/IWF

6



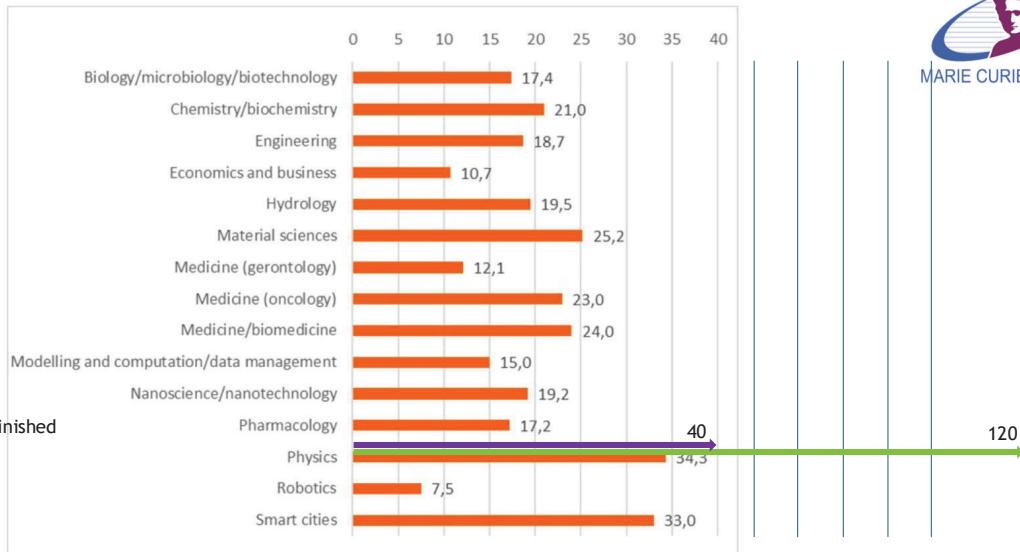
MARIE CURIE ACTIONS

## CHAMELEON Achievements in the context of EU survey of MC ITNS

 domain averaged  
publication numbers

 MC ITN 2014-2017, all finished  
118 projects analysed

(Bitsios et al. 2023)



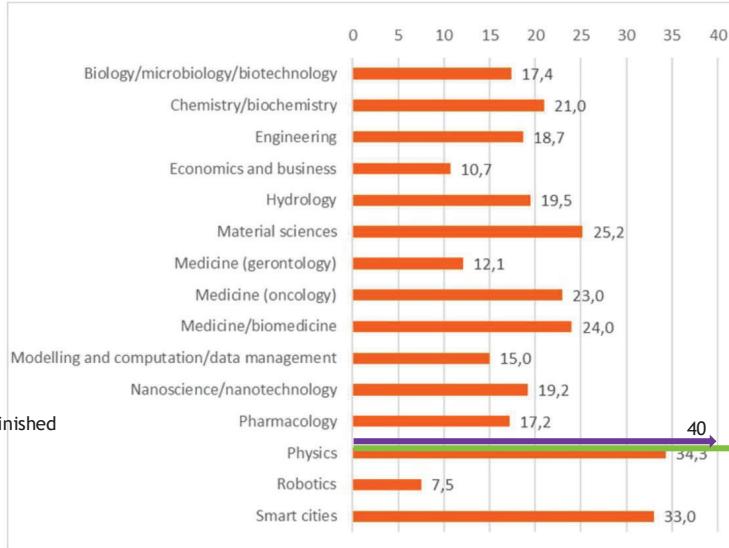
MARIE CURIE ACTIONS

## CHAMELEON Achievements in the context of EU survey of MC ITNS

 domain averaged  
publication numbers

 MC ITN 2014-2017, all finished  
118 projects analysed

(Bitsios et al. 2023)


 Science research  
papers only!

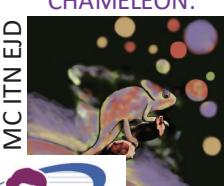
Publications					
Year	Type	Status	Author	Main Research Question	
1	Uncertainties in the physical sciences in relation to major scientific and technological challenges for future space exploration	Published	Combining editor: Miles Nyeon, Ann Bartlett, Alan Hartman, Long S. Adamson, Ann Peters, Eric Fossum	How can analogies, virtual reality, open science workshops (CTIO), and multidisciplinary research (MCITNS) provide opportunities for regional, local and international students to engage in regional and diversity the concept of astrophysics research?	
2	Advances in the interactions between scientists from different fields facilitate a transdisciplinary climate change and space exploration	Published	Second editor: Miles Nyeon, Peter Stevens, Grzegorz Mazurek, James Kang, Michael Bird, Agnieszka Banas, Ann Peters, Zina Erdle	How can we facilitate a transition in climate change and space exploration through recycling analogy?	
3	Engines of Discovery: Interactions between theoretical astrophysics and Space Exploration Using Stellar Evolution Theory Based on the ESS	Published	Combining editor: A.C.J. Meech, Diego Adriani, Peter Stevens, Natalia Ivanova, Alan Pettini, James Kang, Michael Bird, Agnieszka Banas, Miles Nyeon	How can interdisciplinary approaches, involving theoretical, experimental, observational, and space missions, contribute to creating new areas of research and reflecting on humanity's future in space?	
4	The major importance of art and culture in the expansion of the frontiers of Earth space at the European Space Agency	Accepted	Summary editor: Peter Stevens, Miles Nyeon, Michael Bird, Agnieszka Banas, James Kang, Miles Mazurek, Michael Vannier, Miles Nyeon, Van Damme, Agnieszka C.J. Meech	How do Earth frontiers serve as a progenitor for art and culture? How can art and culture contribute to the expansion of our scientific knowledge in the sciences in the Engines of Discovery project?	
5	Horizon: The engagement of art and culture in the expansion of the frontiers of Earth space at the European Space Agency	Journal OEAW 2023	Combining editor: Ulrich Endehart, Miles Nyeon, Michael Bird, Agnieszka Banas, James Kang, Miles Mazurek, Michael Vannier	How can collaborations on practice used to investigate and support interdisciplinary (EU) research to promote arts and culture research and socio-academic collaborations?	
6	Co-creation issues in the post-Anticipate phase	Proceeding OEAW 2022	First author: Peter Stevens, Agnieszka Banas, Miles Nyeon, Grzegorz Mazurek, James Kang, Michael Bird, Michael Vannier, Paul	What are the potential future opportunities for co-creation among scientists, artists, and first and second line cultural institutions to support arts and culture in research and discovery in various fields?	

Title	Description	Theory	Data	Writing Progress	Journal
Clouds on Other Planets	Teaching cloud formation in a high school classroom using inquiry-based learning and cutting-edge exoplanet research	Inquiry-Based Science Education	Lesson material development documents	Published	Jaarboek De Ardijkskun d
The development of an IBSE lesson using contemporary astrophysics research topics	An assessment of the methods used to develop the initial lessons. This will detail the input from the Scientist Teacher Partnerships during the Design-based research process	Scientist-Teacher Partnerships Inquiry-Based Science Education	Recordings from interviews, co-creation and feedback sessions with scientists and teachers	To be submitted in Summer 2024 (Finalising data analysis & results)	Astronomy Education Journal
Students Reactions to Inquiry-Based Science Lessons	A network analysis of student feedback that looks at how students react to the IBSE lesson developed for this project	Inquiry-Based Science Education Network Analysis	Written student feedback from lessons	To be submitted in June 2024 (Finalised - currently in internal revisions before submitting)	International Journal of Science Education
Students Uses and Limitations of Experiments as Physical Analogies	Framing experiments as physical analogies and analyzing the ways in which students use them as such in discussions about the topic.	Conceptual Metaphor Theory Analogical Scaffolding	Recordings of peer-lead interviews that were held after lessons	Accepted for GIREP Conference in August, paper to be submitted after feedback at conference	Science Education
Educational Material Co-Creation Leading to Scientific Collaborations	A description of the creation of lesson materials that use real data from exoplanet scientists	Didactic Transposition - Moving 'backwards' from 'knowledge to be taught' to 'scholarly knowledge'	Recordings of development meetings with scientists and written feedback from teachers	Predicted submission Autumn 2024. Data analysis to be conducted during ESEA summer school (August 2024)	Astronomy Education Journal

INSTITUT FÜR WELTRAUMFORSCHUNG



## CHAMELEON Achievements in the context of EU survey of MC ITNS



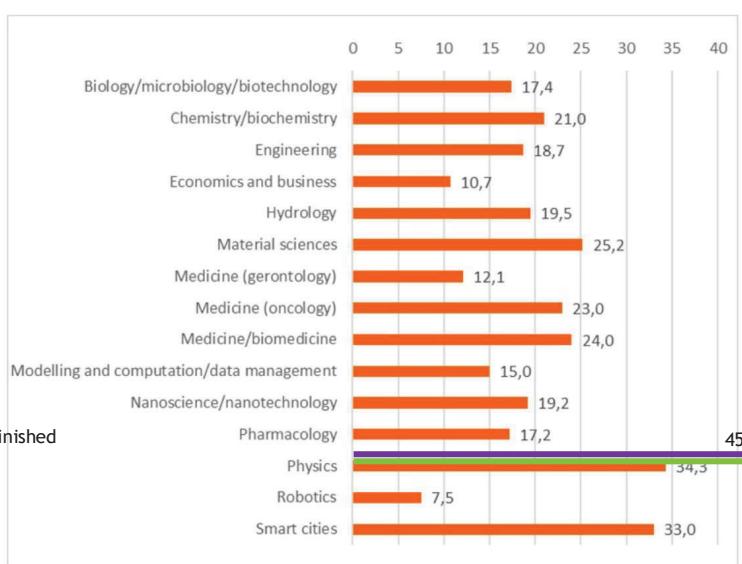
MARIE CURIE ACTIONS

Science, arts &  
education  
research  
publications

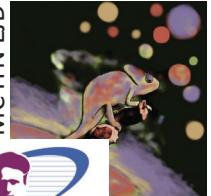
domain averaged  
publication numbers

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(Bitsios et al. 2023)



120



# CHAMELEON School Achievements

School I: getting to know the tools and their background

School II: 4 Space Mission proposals:

## Solar Lens for Observing Terrestrial Habitats

Imaging the surface of an exoplanet: how can we prove extraterrestrial life beyond any reasonable doubt?



Linus Henke



Francisco Andevol Martinez



Merrick Brown

## Planets IN Extragalactic Areas Providing Population Levels: an Enormous Survey

A survey of planets outside of our own galaxy providing large scale exoplanet population statistics



Sven Kiefer



Helena Lecoq Molinos



Aaron Schneider

## PlaDiPro: Circumplanetary Disk Probe

The first steps towards answering the open question of how planets form



Arell Castrejon



Jayatee Kanwar



Thorsten Baldwin



Till Küller



Aditya M. Arabhavi

## Atmospheric Lunar Observatory for Non-Equilibrium

Can we find life on earth-like exoplanets by observing their chemical fingerprints?



Nanna Bach-Møller

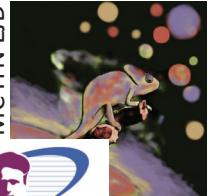


Beatriz Campos Estrada



Ravia Amadio

11



# CHAMELEON School Achievements

School I: getting to know the tools and their background

School II: 4 Space Mission proposals

MEME exhibition

School III: 1 joint paper project on warm Saturn HATS-6b + 1 ALMA proposals + 2 JWST proposals

ESRs photoshoots (see *Huset* exhibition in Copenhagen) + MEME exhibition

Test lessons at local School

	Detecting long hydrocarbons in the protoplanetary disks	None Assigned
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### ABSTRACT

Protoplanetary disks are the cradle of planet formation. The gas mass and chemical composition in these disks are among the most important properties. Knowledge of these quantities is most relevant to understand the planet formation process and the composition of planetary atmospheres. With the high sensitivity of ALMA, we can study the molecular and elemental abundances in these disks and constrain the C/Si/NO elemental ratios. Especially carbon with its chemical flexibility has a huge impact on the disk's chemistry. These ratios can also be measured for the exoplanets thus being a connecting link between disks and planets. We propose to observe the two well-studied bright Herbig disks MWC480 and HD163296 to detect long-chain hydrocarbons in the outer disks to re-evaluate the C/O ratio and determine robustly the total carbon budget in these disks.

SCIENCE CATEGORY:	Circumstellar disks, exoplanets and the solar system				
ESTIMATED 12-M TIME:	15.1 h	ESTIMATED 7-M TIME:	0.0 h	ESTIMATED TP TIME:	0.0 h
DUPLICATE OBSERVATION JUSTIFICATION:	None of the sources have been observed in Band 3 with the sensitivity high enough to observe the targeted molecular lines.				

## Under the magnifying glass: A combined 3D model applied to cloudy warm Saturn type exoplanets around M-dwarfs

S. Kiefer<sup>1,2,3</sup>, N. Bach-Møller<sup>2,3,4</sup>, D. Samra<sup>2</sup>, D. A. Lewis<sup>2,3</sup>, A. D. Schneider<sup>1,4</sup>, F. Amadio<sup>4,1</sup>, H. Lecoq-Molinos<sup>2,3,1</sup>, L. Carone<sup>2</sup>, L. Decin<sup>1</sup>, U. G. Jørgensen<sup>4</sup>, and Ch. Helling<sup>2,3</sup>

<sup>1</sup> Institute of Astronomy, KU Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium

e-mail: sven.kiefer@kuleuven.be

<sup>2</sup> Space Research Institute, Austrian Academy of Sciences, Schmiedlstrasse 6, A-8042 Graz, Austria

<sup>3</sup> Institute for Theoretical Physics and Computational Physics, Graz University of Technology, Petersgasse 16 8010 Graz

<sup>4</sup> Centre for ExoLife Sciences, Niels Bohr Institute, Øster Voldgade 5, 1350 Copenhagen, Denmark

(under review)

# CHAMELEON Achievements from ESR teams



Sven Kiefer



Nanna Bach-Møller



Aaron Schneider



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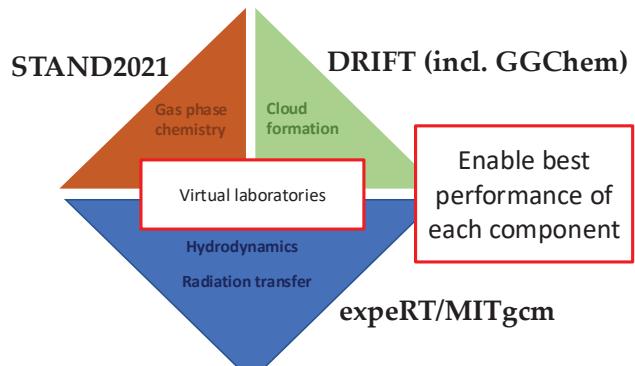
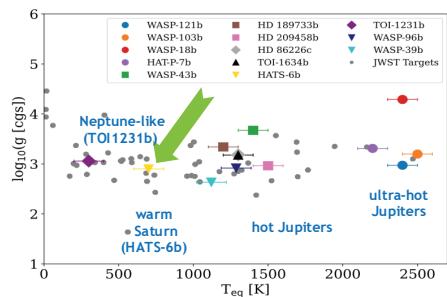


Flavia Amadio



Helena Lecoq M.

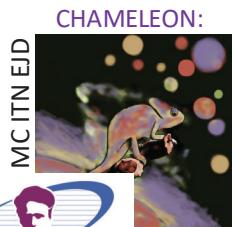
## HATS-6B A WARM SATURN ORBITING AN M-DWARF



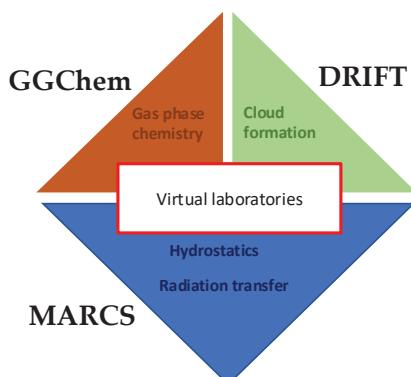
13

## A grid of self-consistent MSG (MARCS-StaticWeather-GGchem) cool stellar, sub-stellar, and exoplanetary model atmospheres

Uffe G. Jørgensen<sup>1</sup>, Flavia Amadio<sup>1,2</sup>, Beatriz Campos Estrada<sup>1,3</sup>, Kristian Holten Møller<sup>1</sup>, Aaron D. Schneider<sup>1,2</sup>, Thorsten Balduin<sup>1,3</sup>, Azzurra D'Alessandro<sup>1</sup>, Eftychia Symeonidou<sup>1,4</sup>, Christiane Helling<sup>3</sup>, Åke Nordlund<sup>1,5</sup>, and Peter Woitke<sup>3</sup>



MARIE CURIE ACTIONS



- Enables to model two major science cases with one tool:
- Young, self luminous planets (+ brown dwarfs)  
(complete grid in **Campos Estrada et al. 2024**, submitted)
  - Old, irradiated planets  
(complete grid in **Amadio et al. 2024**, in preparation)

# CHAMELEON Achievements that open new avenues

**Revisiting fundamental properties of TiO<sub>2</sub> nanoclusters as condensation seeds in astrophysical environments\***

## Vanadium oxide clusters in substellar atmospheres

### A quantum chemical study

H. Lecoq-Molinos<sup>1,2,3</sup>, D. Gobrecht<sup>4</sup>, J.P. Sindel<sup>1,2,5,6</sup>, Ch. Helling<sup>1,3</sup>, and L. Decin<sup>2</sup>

<sup>1</sup> Space Research Institute, Austrian Academy of Sciences, Schmiedlstrasse 6, A-8042 Graz, Austria  
e-mail: janphil@oeaw.ac.at  
<sup>2</sup> Centre for Exoplanet Science, University of St Andrews, North Haugh, St Andrews, KY169SS, UK  
<sup>3</sup> SUPA, School of Physics & Astronomy, University of St Andrews, North Haugh, St Andrews, KY169SS, UK  
<sup>4</sup> Institute for Astrophysics, University of Gothenburg, Sweden  
<sup>5</sup> Department of Chemistry and Molecular Biology, University of Gothenburg, Sweden  
<sup>6</sup> TU Graz, Fakultät für Physik und Geodäsie, Petersgasse 16, A-8010 Graz, Austria

<sup>1</sup> Space Research Institute, Austrian Academy of Sciences, Schmiedlstrasse 6, A-8042 Graz, Austria  
e-mail: helena.lecoq@oeaw.ac.at

<sup>2</sup> Institute of Astronomy, KU Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium

<sup>3</sup> TU Graz, Fakultät für Mathematik, Physik und Geodäsie, Petersgasse 16, A-8010 Graz, Austria

<sup>4</sup> Department of Chemistry and Molecular Biology, University of Gothenburg, Sweden

<sup>5</sup> Centre for Exoplanet Science, University of St Andrews, North Haugh, St Andrews, KY169SS, UK

<sup>6</sup> SUPA, School of Physics & Astronomy, University of St Andrews, North Haugh, St Andrews, KY169SS, UK

CHAMELEON:



Heterogeneous  
seed formation

ML treatment of  
nucleation:  
third-body  
funding  
(1PhD, 1 PostDoc)

**FWF**

Der Wissenschaftsfonds.

# CHAMELEON Achievements that open new avenues

## Bayesian Analysis of Molecular Emission and Dust Continuum of Protoplanetary Disks

T. Kaeufer<sup>1,2,3,4</sup>, M. Min<sup>3</sup>, P. Woitke<sup>1</sup>, I. Kamp<sup>2</sup>, and A. M. Arabhavi<sup>2</sup>

<sup>1</sup> Space Research Institute, Austrian Academy of Sciences, Schmiedlstrasse 6, A-8042 Graz, Austria  
e-mail: till.kaeufer@oeaw.ac.at

<sup>2</sup> Kapteyn Astronomical Institute, University of Groningen, PO Box 800, 9700 AV Groningen, The Netherlands

<sup>3</sup> SRON Netherlands Institute for Space Research, Nieuwegeinweg 4, 2333CA Leiden, The Netherlands

<sup>4</sup> Institute for Theoretical Physics and Computational Physics, Graz University of Technology, Petersgasse 16, 8010 Graz, Austria

CHAMELEON:



MARIE CURIE ACTIONS

## FlopPITy: enabling self-consistent exoplanet atmospheric retrievals with machine learning.

F. Ardévol Martínez<sup>1,2,3,4</sup>, M. Min<sup>2</sup>, D. Huppenkothen<sup>2</sup>, I. Kamp<sup>1</sup>, and P. I. Palmer<sup>3,4</sup>

<sup>1</sup> Kapteyn Astronomical Institute, University of Groningen, Groningen, The Netherlands  
e-mail: ardevol@astro.rug.nl

<sup>2</sup> Netherlands Space Research Institute (SRON), Leiden, The Netherlands

<sup>3</sup> Centre for Exoplanet Science, University of Edinburgh, Edinburgh, UK

<sup>4</sup> School of GeoSciences, University of Edinburgh, Edinburgh, UK

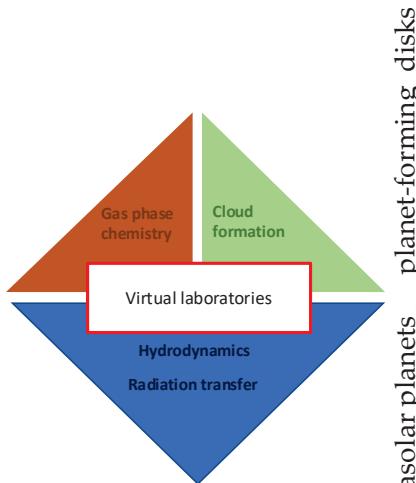
JWST data  
interpretation



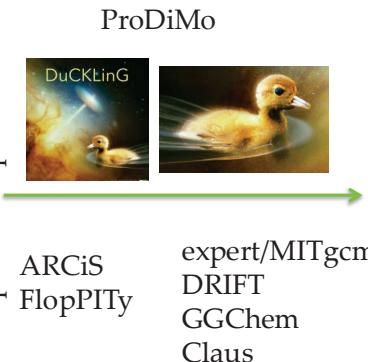


MARIE CURIE ACTIONS

# CHAMELEON JWST Achievements



extrasolar planets planet-forming disks



42-1  
JWST CHAMELEON papers  
50/50 planets/disk

full:"860470" year:2020-2025 abs:"JWST"

- 1  2024arXiv240705070T 2024/07 15  2024Natur.625..51D 2024/01 cited: 24 SO<sub>2</sub>, silicate clouds, but no CH<sub>4</sub> detected in a warm Neptune Dyrek, Achirwe, Min, Michiel, Decin, Leen, and 43 more
- 2  2024AA..687A.209A 2024/07 16  2024AAA..581A.47V 2024/01 Mid-infrared evidence for iron-rich dust in the multi-ringed inner disk of HD 144432 Varga, J.; Waters, L. B. F. M.; Hogerheijde, M., and 40 more
- 3  2024AA..687A.96F 2024/07 cited: 3 17  2024AAA..581A.22K 2024/01 cited: 5 Hydrocarbon chemistry in the inner regions of planet-forming disks Kanwar, J.; Kamp, I.; Wotke, P., and 3 more
- 4  2024arXiv240510217G 2024/05 18  2024arXiv231203424W 2023/12 Physico-chemical Processes in Planet-forming Discs Wotke, Peter
- 5  2024arXiv240510217G 2024/05 19  2023Natur.624..253B 2023/12 cited: 7 <sup>15</sup>NH<sub>3</sub> in the atmosphere of a cool brown dwarf Barrado, David; Molliere, Paul; Patapis, Polychronis, and 40 more
- 6  2024AA..686A.109A 2024/05 cited: 2 20  2023ApJ...958L..30R 2023/12 cited: 5 XUE: Molecular Inventory in the Inner Region of an Extremely Irradiated Protoplanetary Disk Ramírez-Tannus, María Claudia; Bik, Arjan; Cuipers, Lars, and 24 more
- 7  2024AA..686A.117T 2024/06 cited: 3 21  2023AN...34430075J 2023/12 cited: 1 The sulfur species in hot rocky exoplanet atmospheres Janssen, L. J.; Wotke, P.; Herbst, O., and 4 more
- 8  2024AA..686A.105Y 2024/05 22  2023AA..680A.655 2023/12 Infrared spectra of TiO<sub>2</sub> clusters for hot Jupiter atmospheres Sindel, J. P.; Helling, Ch.; Gobrecht, D., and 2 more
- 9  2024PASP..136e4302H 2024/05 cited: 10 23  2023AA..679A.117G 2023/11 cited: 21 MINDS: Abundant water and varying C/O across the disk of Sz 98 as seen by JWST/MIRI Gasman, Danny; van Dishoeck, Ewine F.; Grant, Sierra L., and 41 more
- 10  2024AA..685A..63A 2024/05 cited: 1 24  2023AAA..579A.92P 2023/11 cited: 3 CHEOPS and TESS view of the ultra-short-period super-Earth TOI-561 b Patel, J. A.; Egger, J. A.; Wilson, T. G., and 75 more
- 11  2024Natur.6mp...1B 2024/04 cited: 6 25  2023FaDi..245..112K 2023/09 cited: 10 The chemical inventory of the inner regions of planet-forming disks — the JWST/MIND program Kamp, Inga; Henning, Thomas; Arabhavi, Aditya M., and 40 more
- 12  2024AA..683A.219W 2024/03 cited: 5 26  2023FaDi..245..52V 2023/09 cited: 17 The diverse chemistry of protoplanetary disks as revealed by JWST van Dishoeck, Ewine F.; Grant, S.; Tabone, B., and 14 more
- 13  2024AA..682A..85 2024/02 cited: 4 27  2023AAA..677A.36B 2023/09 cited: 5 TOI-2084 b and TOI-4184 b: Two new sub-Neptunes around M-dwarf stars Barkaoui, K.; Timmermans, M.; Soubkiou, A., and 67 more
- 14  2024AA..682A.150K 2024/02 Fully time-dependent cloud formation from a non-equilibrium gas-phase in exoplanetary atmospheres Keifer, S.; Lecoq-Molinos, H.; Helling, Ch., and 2 more
- 28  2023Natur.620..516P 2023/06 cited: 34 Water in the terrestrial planet-forming zone of the PDS 70 disk Perotti, G.; Christiaens, V.; Henning, Th., and 42 more
- 29  2023Natur.627..805T 2023/07 cited: 49 A rich hydrocarbon chemistry and high C to O ratio in the inner disk around a very low-mass star Tabone, B.; Bettini, G.; van Dishoeck, E. F., and 43 more
- 30  2023Natur.617..483T 2023/05 cited: 100 Photochemically produced SO<sub>2</sub> in the atmosphere of WASP-39b Tsai, Shang-Min; Lee, Elspeth K. H.; Powell, Diana, and 82 more
- 31  2023ApJ...947L..6G 2023/04 cited: 43 MINDS: The Detection of <sup>13</sup>CO<sub>2</sub> with JWST-MIRI Indicates Abundant CO<sub>2</sub> in a Protoplanetary Disk Grant, Sierra L.; van Dishoeck, Ewine F.; Tabone, Benoot, and 43 more
- 32  2023AA..671A.122H 2023/03 cited: 18 Exoplanet weather and climate regimes with clouds and thermal ionospheres. A model grid test in support of large-scale observational campaigns Helling, Christiane; Samra, Dominic; Lewis, David, and 7 more
- 33  2023arXiv230108492C 2023/01 cited: 5 WASP-39b: exo-Saturn with patchy cloud composition, moderate metallicity, and underdepleted S/O Carone, Ludmila; Lewis, David A.; Samra, Dominic, and 2 more
- 34  2023AAA..659A.142S 2023/01 cited: 13 Clouds form on the hot Saturn JWST ERO target WASP-96b Samra, D.; Helling, Ch.; Chubb, K. L., and 3 more
- 35  2022AAA..663A.47S 2022/07 cited: 7 Mineral snowflakes on exoplanets and brown dwarfs. Coagulation and fragmentation of cloud particles with HYLANDS Samra, D.; Helling, Ch.; Birnstiel, T.
- 36  2022AAA..662A.108A 2022/06 cited: 13 Convolutional neural networks as an alternative to Bayesian retrievals for interpreting exoplanet transmission spectra Ardevol Martinez, F.; Min, M.; Kamp, I., and 1 more
- 37  2022arXiv220301236A 2022/03 cited: 8 Convolutional neural networks as an alternative to Bayesian retrievals Ardevol Martinez, Francisco; Min, Michiel; Kamp, Inga, and 1 more
- 38  2021EPSC..15..713A 2021/09 Machine learning as an ultra-fast alternative to Bayesian retrievals Ardevol Martinez, Francisco; Min, Michiel; Kamp, Inga, and 1 more
- 39  2021AAA..649L..5B 2021/05 cited: 35 Dry or water world? How the water contents of inner sub-Neptunes constrain giant planet formation and the location of the water ice line Bitsch, Bertram; Raymond, Sean N.; Buchhave, Lars A., and 3 more
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# CHAMELEON Achievements exoplanet and disk research connection & heritage

particle charging & lightning

## IONIZATION IN ATMOSPHERES OF BROWN DWARFS AND EXTRASOLAR PLANETS. III. BREAKDOWN CONDITIONS FOR MINERAL CLOUDS

CH. HELLING<sup>1</sup>, M. JAMES<sup>1</sup>, C. STACEY<sup>1</sup> AND D. DIVER<sup>2</sup>  
<sup>1</sup>SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews KY16 9SS, UK, ch.hell@supa2010.ac.uk  
<sup>2</sup>SUPA, School of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, UK  
 Received 2012 July 6; accepted 2013 January 30; published 2013 April 5

Dust cloud lightning in extraterrestrial atmospheres

Christiane Helling<sup>a</sup>, Moira Jardine<sup>b</sup>, Declan Diver<sup>b</sup>, Søren Witte<sup>c</sup>

Atmospheric electrification in dusty, reactive gases in the solar system and beyond

Christiane Helling<sup>1</sup>, R. Giles Harrison<sup>2</sup>, Farideh Honary<sup>3</sup>, Declan A. Diver<sup>4</sup>, Karen Aplin<sup>5</sup>, Ian Dobbs-Dixon<sup>6</sup>, Ute Ebert<sup>7</sup>, Shu-ichiro Inutsuka<sup>8</sup>, Francisco J. Gordillo-Vazquez<sup>9</sup>, Stuart Littlefair<sup>10</sup>

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## Aggregation and charging of mineral cloud particles under high-energy irradiation

NANNA BACH-MØLLER<sup>1,2,3</sup>, CHRISTIANE HELLING<sup>1,2,3</sup>, UFFE G. JØRGENSEN<sup>1</sup> AND MARTIN B. ENGHOFF<sup>1,4</sup>

<sup>1</sup>Centre for ExoLife Sciences, Niels Bohr Institute, Øster Voldgade 5, 1350 Copenhagen, Denmark

<sup>2</sup>Space Research Institute, Austrian Academy of Science, Schmiedelstraße 6, 8042 Graz, Austria

**Lightning-induced chemistry on tidally-locked Earth-like exoplanets**, 8010 Graz, Austria

Merrick Braam<sup>1,2,3\*</sup>, Paul I. Palmer<sup>1,2</sup>, Leen Decin<sup>3</sup>, Robert J. Ridgway<sup>1,4</sup>, Maria Zamyatina<sup>1,4</sup>, Nathan J. Mayne,<sup>4</sup> Denis E. Sergeev<sup>4</sup> and N. Luke Abraham<sup>5,6</sup>

<sup>1</sup>School of GeoSciences, University of Edinburgh, Edinburgh, EH9 3FF, UK

<sup>2</sup>Centre for Exoplanet Science, University of Edinburgh, Edinburgh, EH9 3FD, UK

<sup>3</sup>Institute of Astronomy, University of Cambridge, Cambridge, CB3 0HA, UK

<sup>4</sup>Department

<sup>5</sup>Yusuf Ham

<sup>6</sup>National C

## Size-dependent charging of dust particles in protoplanetary disks

**Can turbulence cause charge separation and lightning?**

T. Balduin<sup>1,2,3</sup>, P. Woitke<sup>1,2</sup>, U. G. Jørgensen<sup>3</sup>, W.-F. Thi<sup>4</sup> and Y. Narita<sup>1</sup>

<sup>1</sup>Austrian Academy of Science, Space Research Institute, Schmiedlstrasse 6, A-8042 Graz, Austria  
 e-mail: Thorsten.Balduin@oeaw.ac.at

<sup>2</sup>TU Graz, Faculty of Mathematics, Physics and Geodesy, Petersgasse 16, 8010 Graz, Austria

<sup>3</sup>Centre for ExoLife Sciences (CELS), Niels Bohr Institute, Østervoldgade 5, DK-1350 Copenhagen, Denmark

<sup>4</sup>Max Planck Institute for Extraterrestrial Physics, Giessenbachstrasse 1, D-85748 Garching, Germany

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# CHAMELEON Achievements exoplanet and disk research connection + education

particle charging & lightning

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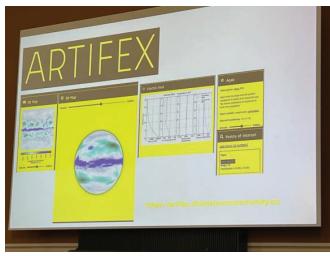
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**ARTIFEX: Exoplanet atmosphere visualisation**

**Authors:** Pieter Stuyten, Marnick Braam, Thorsten Baldwin, Orla Marshall, Diego Maranan, Jesper Braun  
**Publication date:** (Print) July 2024  
**Conference name:** Proceedings of EVA London 2024 (EVA 2024)  
**Conference theme:** Since 1992, the EVA London Conference has established itself as one of the United Kingdom's most innovative and interdisciplinary conferences in the field of digital visualization. The papers and abstracts in this volume cover areas such as the arts, culture, heritage, museums, music, performance, visual art, and visualization, as well as related interdisciplinary areas, in combination with technology. The latest research and work by early career researchers, established scholars, practitioners, research students, and visual artists, can be found in this volume, published in full colour.  
**Conference date:** 8–12 July 2024

**DOI:** <https://doi.org/10.5281/zenodo.7500000>

**f. Introduction**  
 The ongoing discovery and study of exoplanets, especially their atmospheres, are thriving, with significant contributions from instruments like the James Webb Telescope (JWST) (Biller et al. 2022), promising further advancements. Research reveals these planets have unique atmospheres, differing from Earth with phenomena like sand rains on WASP-107b (Dyck et al. 2023). However, representing these atmospheres often relies on graphs (Seeger and Domling 2010). Crossfield (2010) notes that this approach is challenging for the general public to understand without further education or modeling, resulting in mostly static and non-interactive visualizations (Smith et al. 2020).

**2. The Explained EXPLORER project**  
 Through a series of experimental outreach events, a new explorative, interactive visualization method for visualizing exoplanetary atmospheric data has been developed. The Exploring EXPLORER project is an interdisciplinary initiative that blends live-action role-play (Tynan et al. 2006; Beaman 2014) with scientific research to create immersive, interactive experiences for experts and non-experts alike. This method is intended to break down barriers in interpreting abstract representations (Olsen 2018) by translating numerical data into visual narratives. Participants are invited to explore an exoplanet's atmospheric layers visually, deepening their understanding of the scientific models and the relationship between different parameters.

**3. ARTIFEX**  
 The platform's data originates from simulations of exoplanet atmospheres using the UK Met Office's Unified Model, tailored for diverse exoplanets (Migne et al. 2014; Boule et al. 2017; Yates et al. 2020; Serenov et al. 2020; Baldwin et al. 2022). These models simulate the atmospheric conditions of a Sun-like star at Earth's orbital distance, and the climate simulation of the closest exoplanet to Earth, which orbits a colder, smaller star, is tidally locked, and located much closer to its star than Earth is to the Sun. Observational data informs these models to simulate realistic atmospheric conditions, examining effects of stellar radiation, atmospheric composition, and thickness. Wind speed and temperature gradients highlight atmospheric movements, influencing clouds and chemical

**visualizing and understanding exoplanet atmosphere data.**

**Figure 1.** An early version of ARTIFEX for LAPP interventions

In our most recent iteration, presented at the Big Bang Conference on Science Education in Denmark in March 2024, we introduced an innovative visualization method. This method functions simultaneously as a versatile tool, facilitating both scientific analysis and enhancing educational outreach efforts. This new visualization method, named ARTIFEX (ARTistic Interface for scientific Exploration), converts multidimensional data into interactive experiences that cater to both experts and non-experts alike. This method is intended to break down barriers in interpreting abstract representations (Olsen 2018) by translating numerical data into visual narratives. Participants are invited to explore an exoplanet's atmospheric layers visually, deepening their understanding of the scientific models and the relationship between different parameters.

**Figure 2.** The ARTIFEX dashboard for inquiry-based learning activities

These heatmaps are rendered simultaneously both as a 2D canvas and as a 3D spherical representation through UV mapping (Akenine-Möller et al. 2018). The level of height in the atmosphere is controllable, and users are able to select, annotate, and save coordinates. The latest selected coordinates get rendered in a panel of additional graphs, showcasing the relationship between height, wind, temperature, and electric fields. Figure 3 is a schematic representation of the ARTIFEX system.

```

graph TD
    CCAModelSelection[CCM Model Selection] --> AquaPlanetModel[Aqua Planet Model]
    CCAModelSelection --> PCBModel[PCB Planet Model]
    AquaPlanetModel --> ExtrapolateVariables[Extrapolate Variables (Wind, Temperature)]
    PCBModel --> ExtrapolateVariables
    ExtrapolateVariables --> RenderOnPlatform[Render on Platform (2D / 3D Visualization)]
    
```

**Figure 2.** The ARTIFEX dashboard for inquiry-based learning activities

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## CHAMELEON Achievements that connect exoplanet and disk research

kinetic carbon gas-phase chemistry

INSTITUT FÜR WELTRAUMFORSCHUNG

CHAMELEON:



### A CHEMICAL KINETICS NETWORK FOR LIGHTNING AND LIFE IN PLANETARY ATMOSPHERES

P. B. RIMMER AND CH HELLING

School of Physics and Astronomy, University of St Andrews, St Andrews, KY16 9SS, UK; [pr33@st-andrews.ac.uk](mailto:pr33@st-andrews.ac.uk)

Received 2015 June 3; accepted 2015 October 22; published 2016 May 23

extrasolar planets

- Jayatee Kanvar Chapter 4: 3-body process, high/low pressure limit, reaction reversal via thermodynamic data
- New mixing formalism for ProDiMo inspired by ARGO from Rimmer & Helling (2016)

### Mixing and diffusion in protoplanetary disc chemistry

P. Woitke<sup>1,2,3</sup> , A. M. Arabhavi<sup>2,3,4,5</sup>, I. Kamp<sup>4</sup>, and W.-F. Thi<sup>6</sup>

<sup>1</sup> Space Research Institute, Austrian Academy of Sciences, Schmiedlstr. 6, 8042, Graz, Austria

e-mail: [peter.woitke@oeaw.ac.at](mailto:peter.woitke@oeaw.ac.at)

<sup>2</sup> Centre for Exoplanet Science, University of St Andrews, North Haugh, St Andrews, KY16 9SS, UK

<sup>3</sup> School of Physics & Astronomy, University of St. Andrews, North Haugh, St. Andrews KY16 9SS, UK

<sup>4</sup> Kapteyn Astronomical Institute, University of Groningen, PO Box 800, 9700 AV Groningen, The Netherlands

<sup>5</sup> Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, 2629 HS Delft, The Netherlands

<sup>6</sup> Max Planck Institute for Extraterrestrial Physics, Giessenbachstrasse, 85741 Garching, Germany

# CHAMELEON IN SPACE



14 CHAMELEON papers


 42-1 CHAMELEON papers  
50/50 planets/disk


WPs 116700, 116800 (IWF)


 Science Team  
Members:  
SRON, IWF, Leuven


MARIE CURIE ACTIONS

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CHAMELEON: November 2020 kick-off → August 2024 finale



**CHAMELEON**  
Achievements  
exoplanet and  
disk research  
connection  
+ arts

INSTITUT FÜR WELTRAUMFORSCHUNG



## Exploring Exoplanets

All events take place at XENON, which is located on

Join us from Monday, July 29th to Friday, August 2nd, at Huset Copenhagen, a unique space-themed venue. This exhibition is part of the "Exploring Exoplanets" series that seamlessly intertwines art and science. Presented in collaboration with the University of Copenhagen, this event is independently organized.

"Exploring Exoplanets" stems from the research of Pieter Steyaert, a Belgian astronomer and artist who has dedicated his life to the study of exoplanets. The exhibition showcases a limited edition of his artworks, including paintings, photographs, and video installations.

Beyond the exhibition, we offer a series of engaging activities. Enjoy a guided tour of the Huset Copenhagen's space-themed exhibits, learn about the latest discoveries in exoplanet research, and participate in humor and astrophysics with improv comedy from Improv Comedy Copenhagen. Additionally, immerse yourself in the life of an astronomer with our visualization workshops. Additionally, immerse yourself in the life of an astronomer with our visualization workshops. Additionally, immerse yourself in the life of an astronomer with our visualization workshops.

Among the facilitators of these activities are astronomers Anja C. Marshall, space architect and biologist Angelo Vermeulen and a team of artists.

Most activities are conducted in English, with assistance available in Danish.

We look forward to welcoming you to Huset Copenhagen for this exciting week of exploration!

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This project is funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant No 880470



# CHAMELEON THANKS

Research WP leads: **Peter Woitke, Leen Decin, Uffe G. Jørgensen**  
(remember the final reports!)

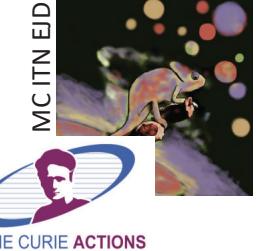
WP Training lead: **Inga Kamp**  
**Michiel Min & Ludmila Carone** (School organization)

WP Recruiting: **Paul Palmer**

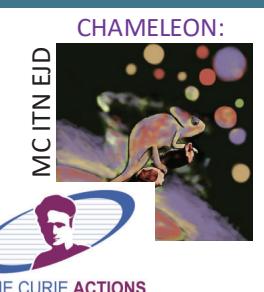
WP Arts & Outreach leads: **Katrien Kolenberg & Anja C. Andersen**

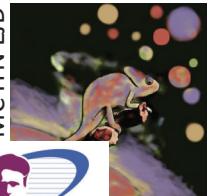
ESR representatives: **Sven Kiefer, Thorsten Balduin, Nanna Bach-Møller, Pieter Steyaert**

All our local administrations, in particular **Ruth-Sophie Taubner**.



# CHAMELEON CONFERENCE IN COPENHAGEN





MC ITN EID



MARIE CURIE ACTIONS

Opening the floor to other supervisors: